Piezoelectric Pump using Innovative Non-Mechanical Valves

DARPA Contract # DAAH01-99-C-R236

SBIR PHASE I

Objectives and scope of Program

- To demonstrate the feasibility of building high energy density pumps utilizing piezoelectric electromechanical actuation and active non mechanical valves.
- Fabrication of prototype pump and valves
- Proof of concept demonstrations

Principal Investigators

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Dr. Quanfang Chen	UCLA

Schedule

Activity Name	Duration
PIEZOELECTRIC PUMP DEV	628
PHASE I - Proof of Concept	197
Kick off Meeting	0
Design Pump	35
Design Prototype Valve	44
Fabrication	45
Test	22
Valve Optimization	64
Pump Characterization	87
Final Report	0
PHASE II - Full Scale Dev	386
Develop Valve, Packaging	117
Develop Low Loss Actuator	118
Modeling to Meet Performance Goal	150
Pump / Bubble Valve Integration	124
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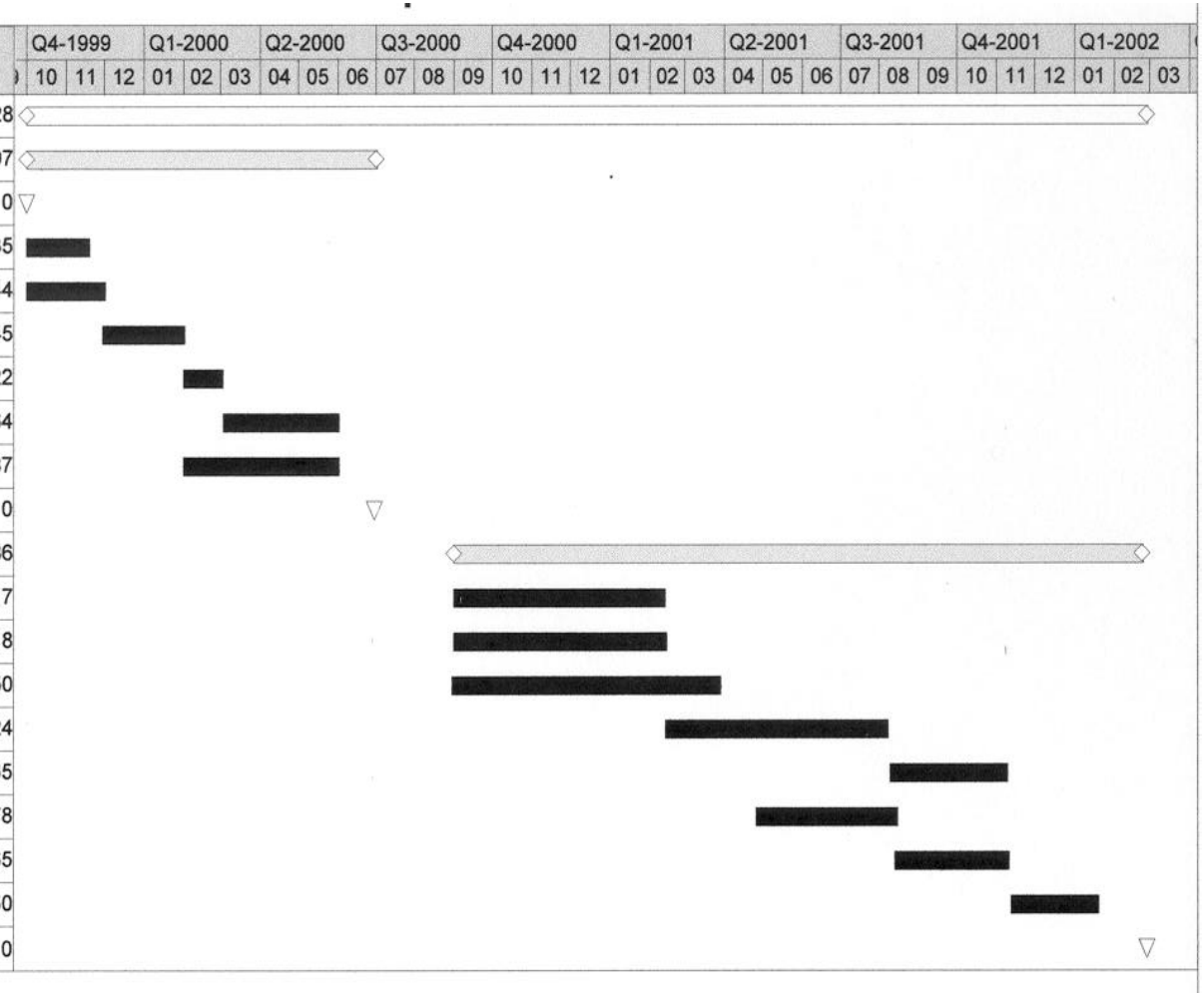
Power Supply Design	78
Power Supply Fabrication	65
Performance Tests & Characterization	50
Final Report	0



Program Responsibilities

- Kinetic Ceramics Inc. - PRIME
  - Design & fabricate a piezoelectric pump capable of operating to 10kHz. Demonstrate pump operation.
  - Task Completed
- UCLA
  - Demonstrate the bubble valve principle by fabricating valves through Silicon micro machining techniques. Characterize valve performance.
  - Task Completed

Major Accomplishments

- Successful fabrication of bubble valve structures in series / parallel arrays.
- Demonstration of the valve operation under dynamic conditions.
- Valve demonstrated to withstand 100 psi so far.
- Demonstration of pump operation with conventional valves.
- Pump demonstration validates goal of 10cc/sec at 10 kHz is attainable.

Lessons Learned & Future Transitions

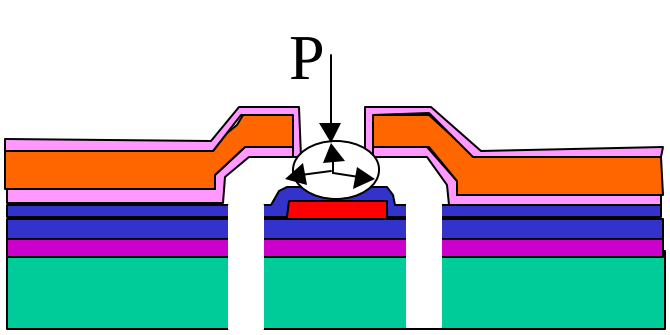
- High frequency Bubble Valve Pump concept is viable.
- In a Phase II program, it is proposed to increase the pump energy density two orders of magnitude by integrating the developed Bubble Valve into the pump. Packaging of the Bubble Valve will be addressed.
- The resulting high energy density pump is scaleable and will become available for a multitude of aerospace actuator and control applications.

Motivation for Bubble Valve

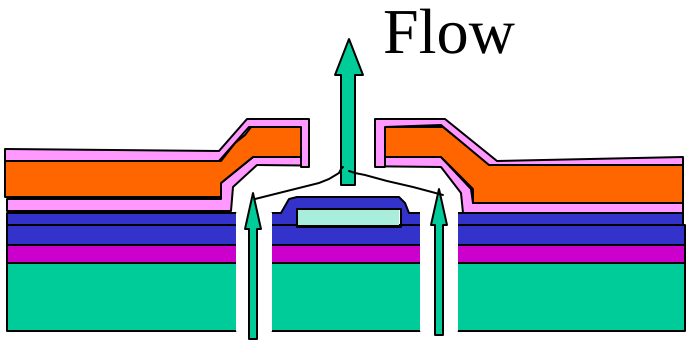
- ***Requirement of Compact Actuator Device***:
  - Active materials have fast response, high force and little displacement. To obtain high power density it is desirable to operate at high pressure and high frequency.
- ***Mechanical check valves:***
  - Low frequency response (less than 200 Hz), fatigue and wear especially with high pressure.
- ***Bubble valve:***
  - High frequency response (2k to 30 kHz) and large pressure drop(1MPa to 3GPa), without fatigue and wear.

Bubble Valve Driving Mechanism

- Valve functions by generating/collapsing a bubble that blocks an orifice.
- Explosive nucleation generates huge pressure differentials.
- Shorter heating time produces higher pressure drop (10 MPa).
- Bubble generation time can range between 100 ns and 100 μs (frequency >10kHz) .

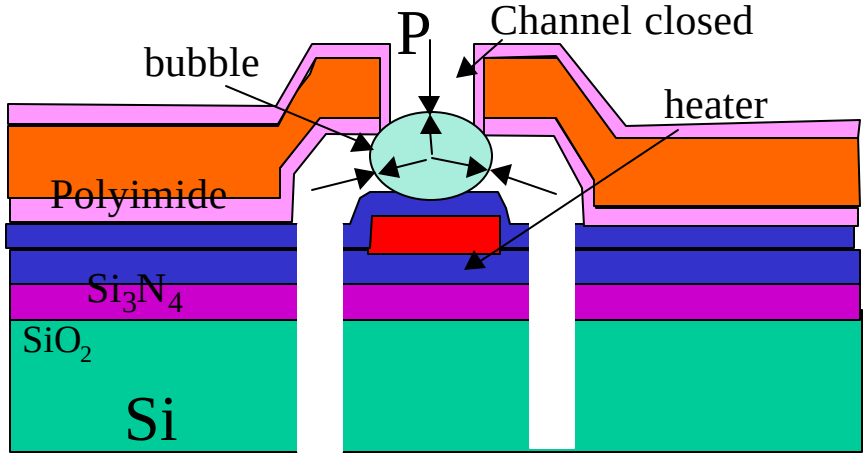


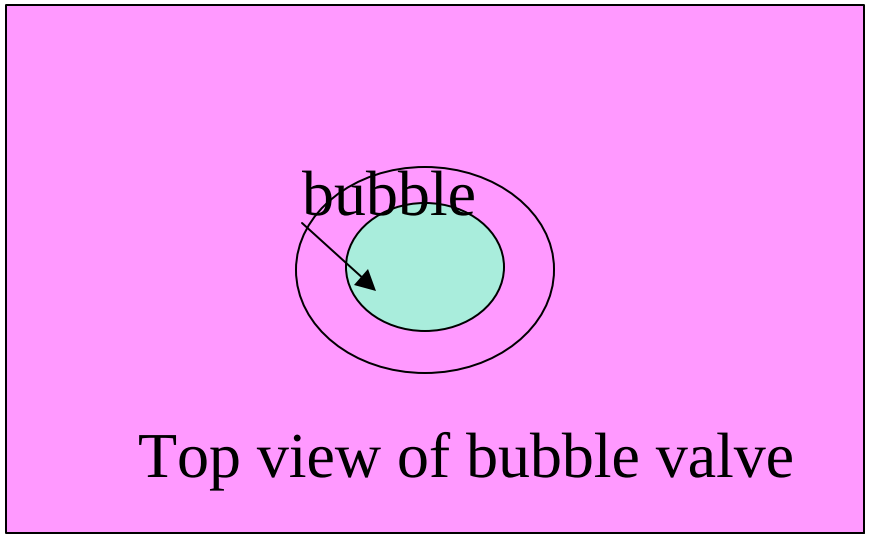
Bubble valve closed



Bubble valve open

Bubble Valve Design





Single valve:

Channel size: 50μm in diameter

Opening area: $A=5x10^{-2}$ mm^2

Array:

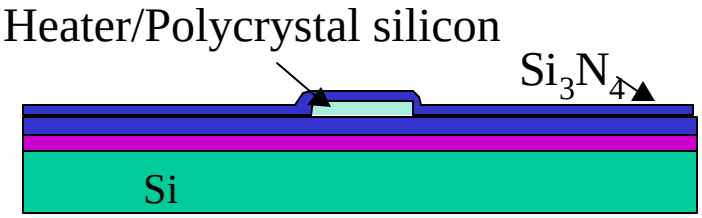
Total opening area required: 1.7 mm^2

Number of valves required: 866

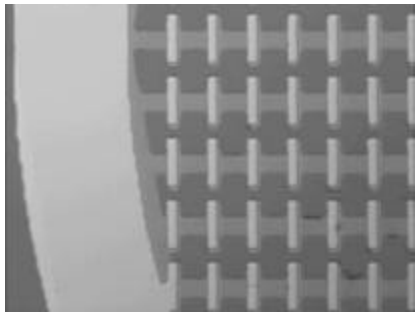
Overall size: 7.5 mm diameter

Flow rate: 10cc/sec

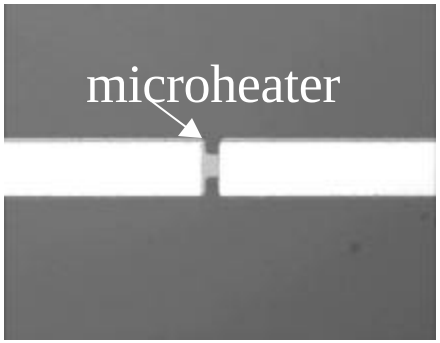
Fabrication of Bubble Valve



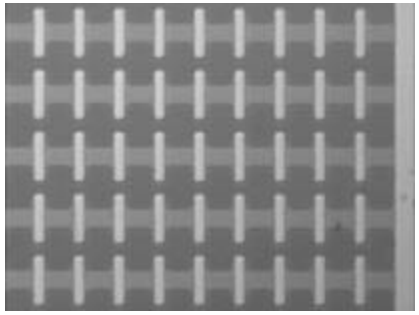
Fabrication process of heater



Integrated heaters, circular arrangement



Top view of fabricated heater



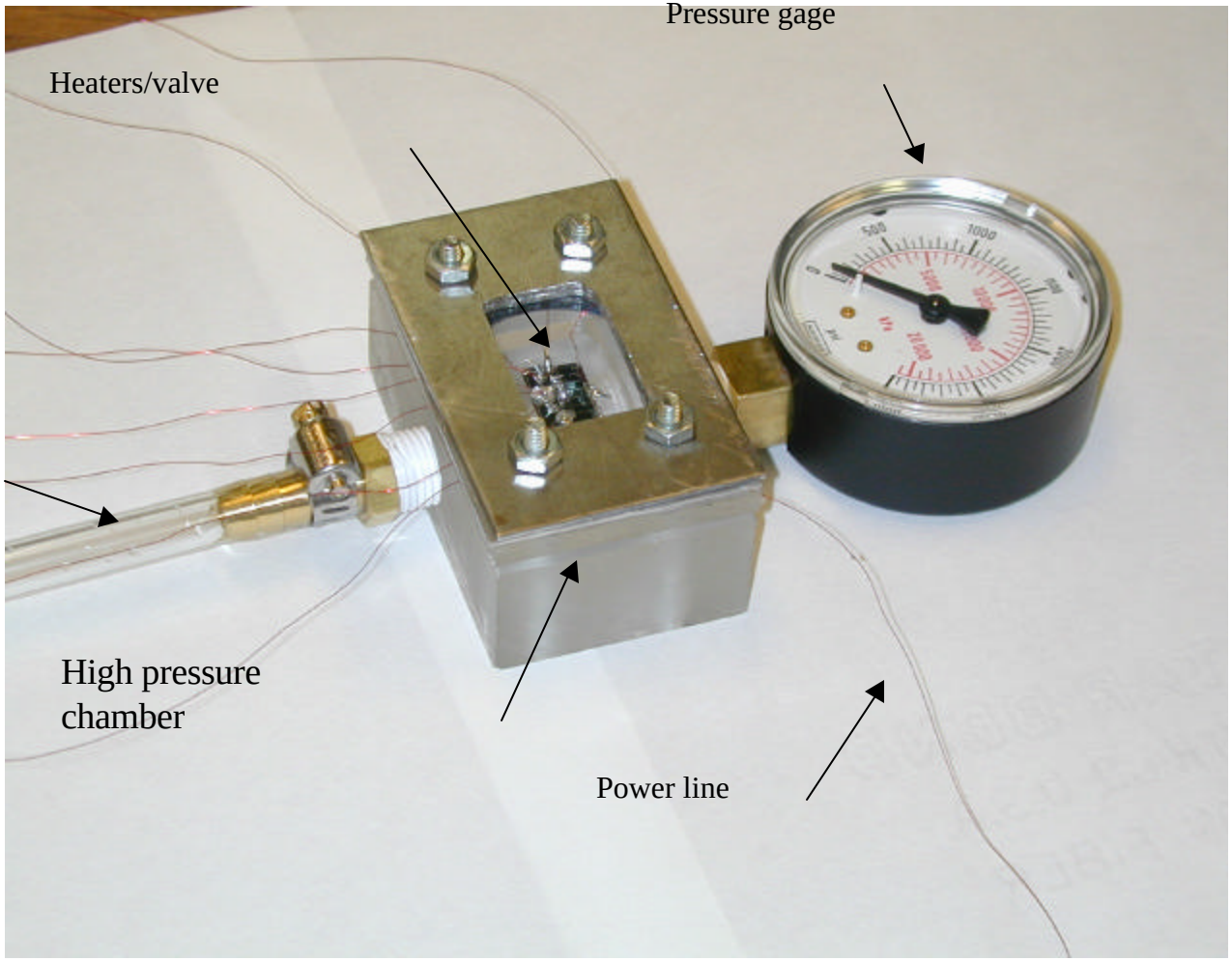
Integrated heaters, rectangular arrangement

- Lithography micromachining method
- Polycrystal silicon microheater
- Integration into an array for large flow rate

Summary
Bubble Valve Development

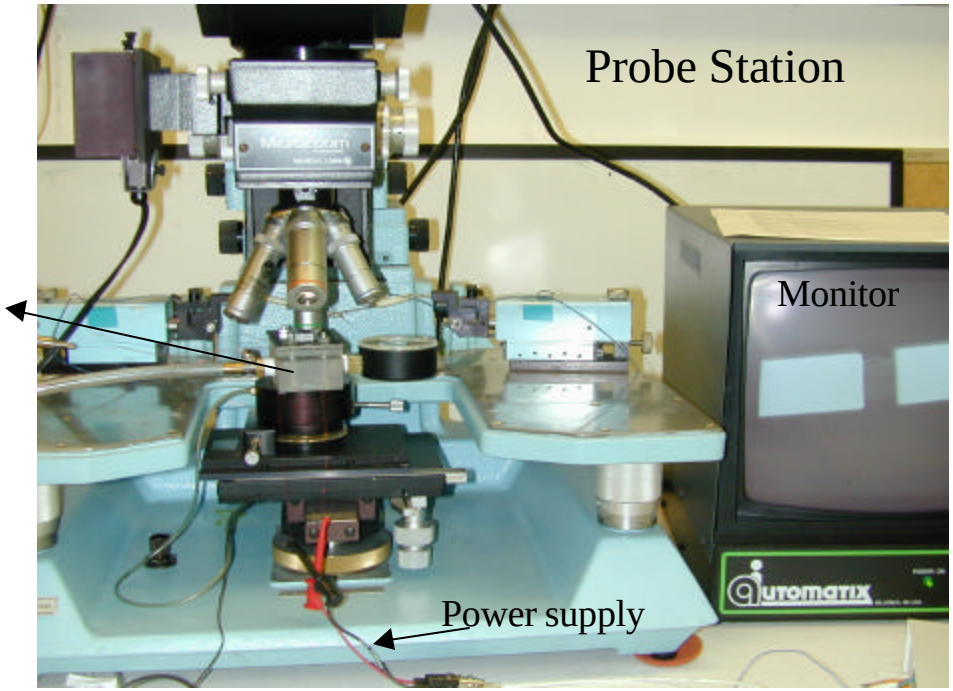
- Bubble valve designed, fabricated and tested.
- Tested successfully with 100psi differential pressure.
- Frequency response verification limited by video recording equipment. Higher frequency response with similar design demonstrated (>10khz).
- Integration of bubble valve with PZT pump will be possible once packaging issues are addressed.

Test Chamber



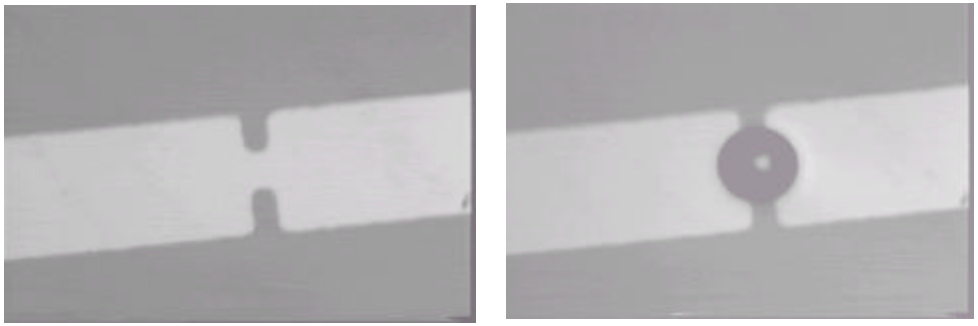
Test Setup for Bubble Valve

High pressure chamber

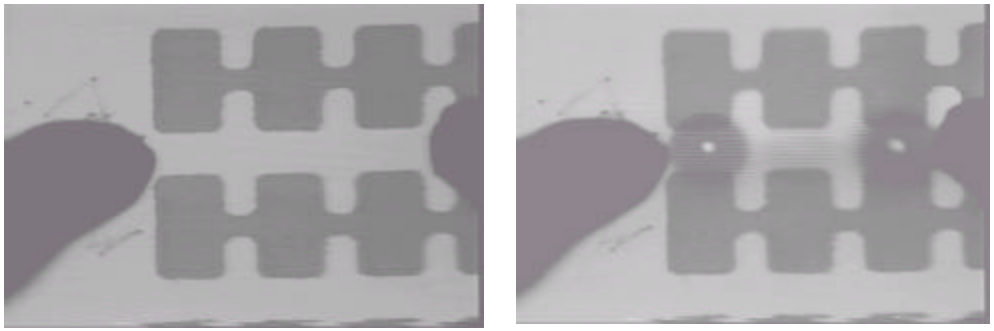


- Transparent view chamber with macro view camera
- Water pump to deliver high pressure
- Bubble valves tested under high pressure

Bubble Testing



Single bubble generated on microheater



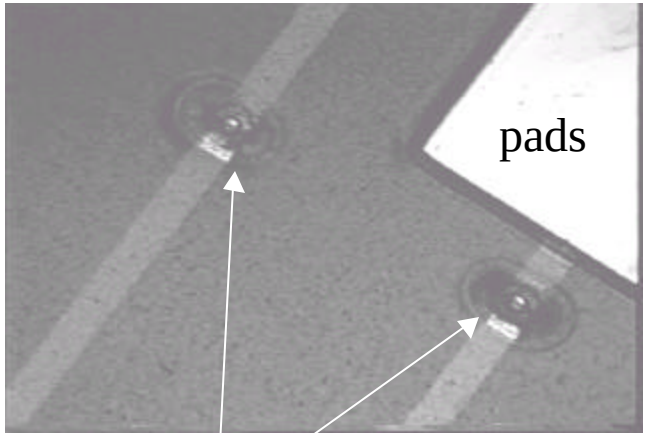
Multiple bubbles generated on microheaters

•Joule heating forms bubble in 10 μs.

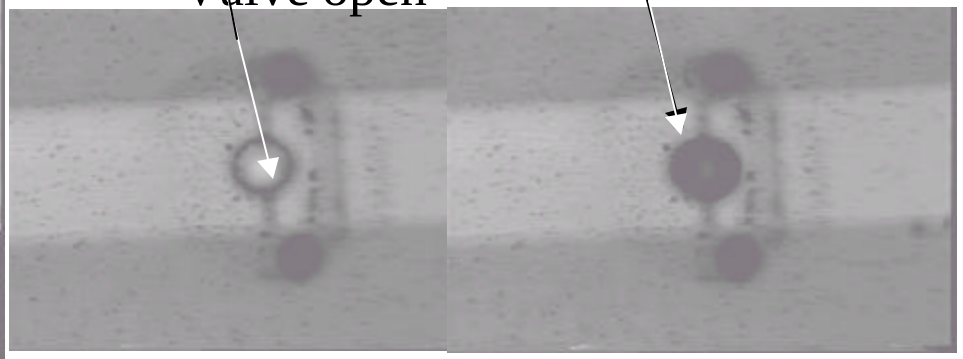
•Series / parallel heaters form multiple bubbles.

•Bubbles generated under hydrostatic pressure (100psi).

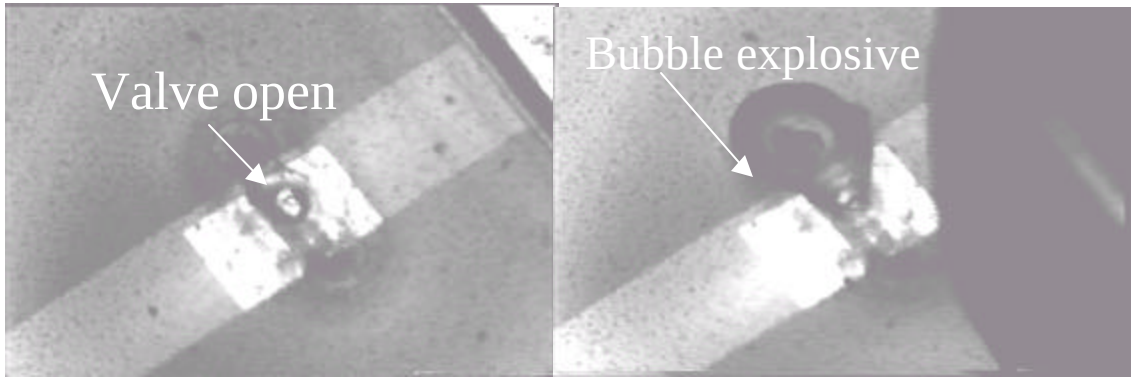
Testing of Bubble Valve



Multiple valves

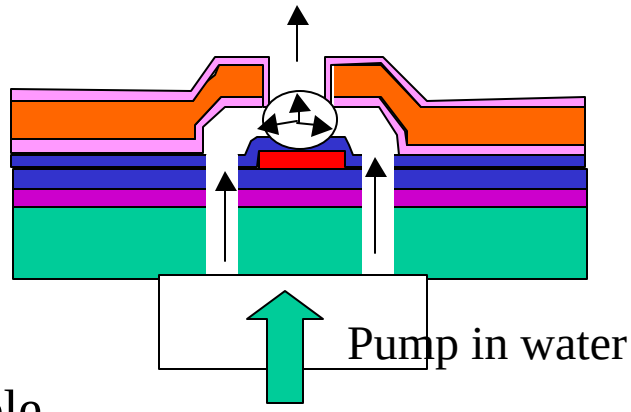


Valve open/closed by bubble



Before pumping

Pumping while heating a bubble, valve closed w/pressure wave distributed



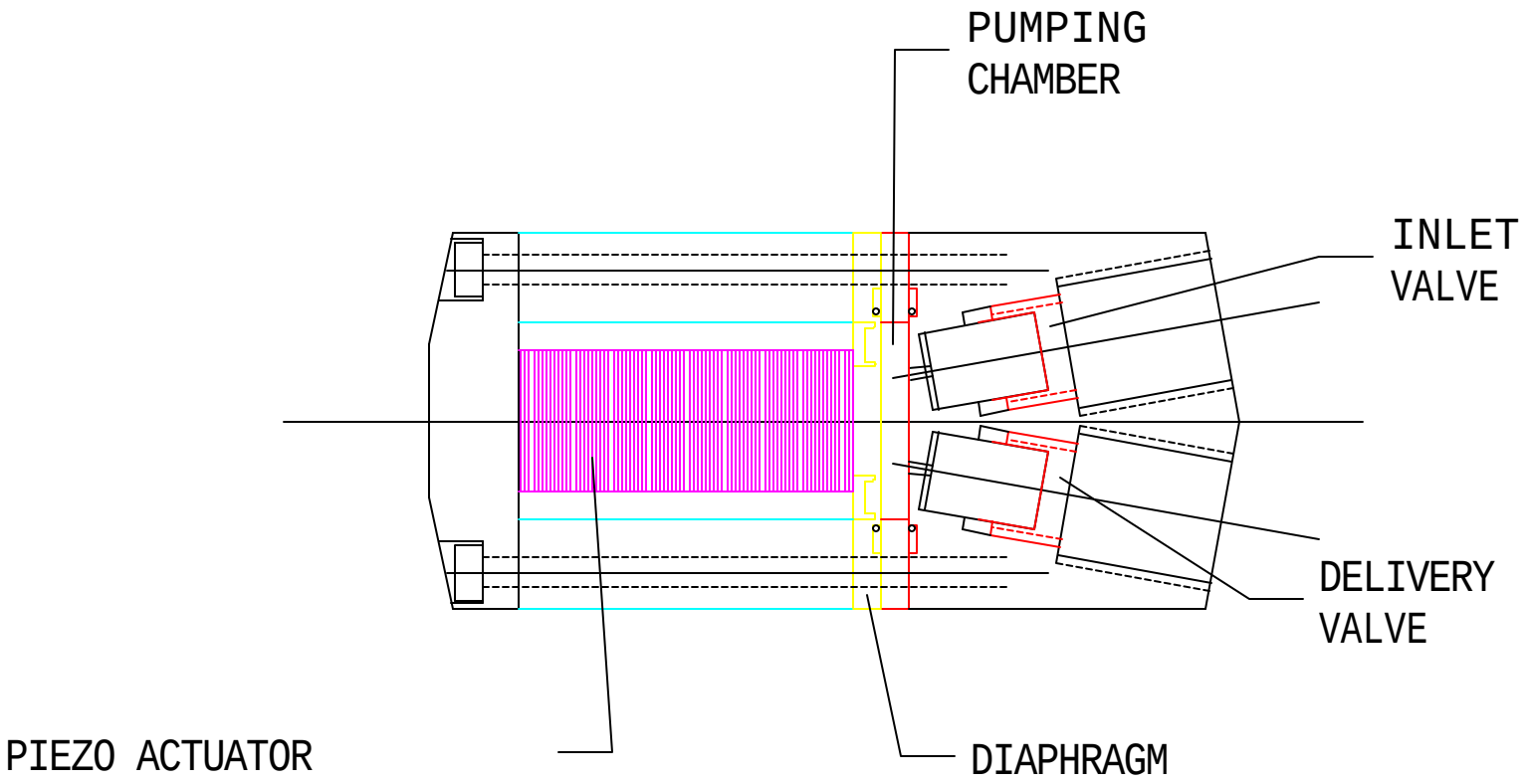
Test setup

Phase I Piezoelectric Pump

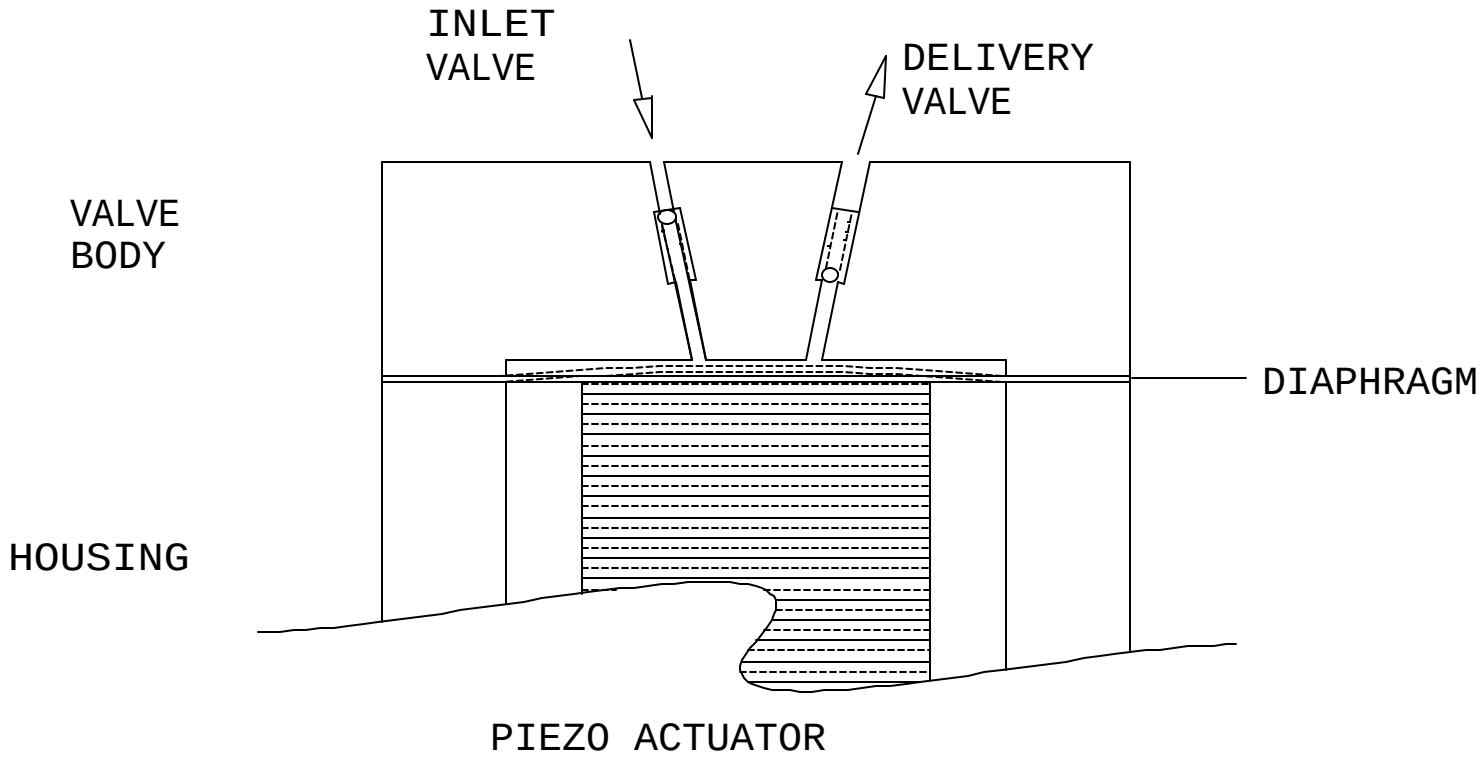
Specifications:

- Diaphragm Pump
- PZWT100 Stack
- Stack volume: 2 cm^3
- Stack mass: 17 g
- Mechanical Valves
- Displacement 5 mm^3

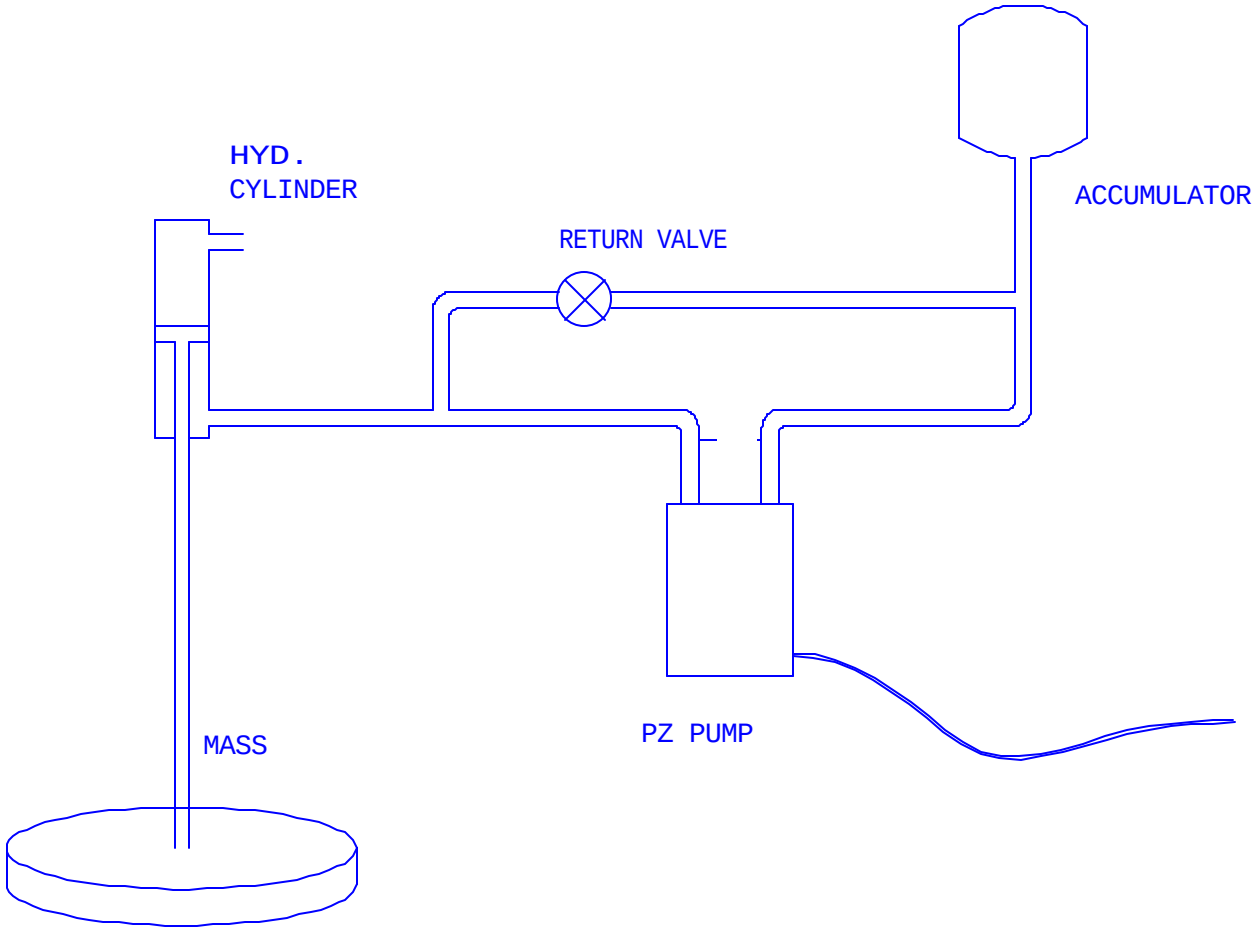
Pump Cross Section



Piezoelectric Pump Operation



Piezoelectric Pump Test Setup



PH I Pump Performance Tests

	PH II Design Goal	PH I Actual
Stall Pressure	600 psi	800 psi
Volume / Stroke	1 mm3	4.0 mm3
Frequency	10kHz	100 Hz*
Flowrate	10 cc / sec	0.4 cc / sec

*Power supply limitation. Mechanical valves predicted to permit operation to 500 Hz.